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THE TECHNICAL AND ECONOMICAL PREPARATION OF INVESTIGATIONS CARRIED OUT WITH ETHANOL-DIESEL OIL MIXTURES

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Abstract

Our investigation took place at the Technical University of Budapest – TUB – where we looked for possible uses of ethanol or an ethanol-diesel mixture in agricultural engines in Hungary. First we examined the international and the Hungarian experiments and as a second step we selected the appropriate engine and procedure.

In this first article we show the preparation of the dyno measurements and the pre-calculations. In the second one the results of the investigations and the added calculations will be described.

The main aspect of the engine selection was to find an engine that is current in Hungary, and to find a procedure which implies only minimal changes on this engine. The procedure – the combination of the possible useful fuels and solutions – was selected through technical, economical and environmental investigations.

Keywords: alternative fuel, bioethanol, biofuel, emission, LCA.

1. Introduction

The environmental pollution and the reduction of the oil-based fuels are the greatest problems of the automotive-industry at the start of the 21st century. There were and certainly there are a lot of experiments to substitute the petrol and the diesel oil with other fuels. One of these substitutes is the ethanol, also called bioethanol, if it is produced from the biomass or from agricultural plants. The ethanol is very similar to the fuels of the present, as it can be used in the engines without any changes in the structure. It is more economical than petrol and diesel oil, because it does not contain any sulphur, so it does not emit any sulphur-oxide. The ethanol's CO_2 net emission is zero, because the amount of emitted carbon-dioxide is equal to the amount that the plants use during photosynthesis.

The Department of Vehicles at the TUB has been searching the possibilities of using alternative fuels for a long time [1, 2, 3]. The target vehicle of the investigations, a flexible fueled vehicle (FFV) has a single fuel tank, fuel system, and engine. The vehicle is designed to run on diesel oil and a mixture of alcohol and diesel oil which contains 15% of ethanol. It is called E-diesel or E15. The engine and fuel system in a flex-fuel vehicle must be adapted slightly to run on alcohol fuels because they are corrosive. The E-diesel vehicle offers its owner an environmentally beneficial option whenever the alternative fuel is available.

The investigations have been carried out on the 10.35 litre Rába D10 engine. This engine, produced in Győr, Hungary, is sold in Hungary and in South Europe in great number of models, for example in buses, trucks and agricultural tractors and staying engines.

2. Facts about Ethanol

2.1. History as Motor Fuel

The usage of ethanol in vehicles is not a new discovery. In the 1880s, Henry Ford built one of his first automobiles to run on ethanol, but ethanol remained a small niche fuel favored by racers for many years. Beginning in the 1970s, several events occurred that led to the introduction of ethanol into the commercial gasoline market. Energy security concerns brought about by the Arabian oil embargo spurred states to enact tax incentives to encourage the production of alternative fuels. Around the same time, concerns about environmental impacts associated with gasoline began to emerge. The banning of lead in gasoline created a demand for blending agents, like ethanol, with a high-octane content. The ethanol is used nowadays as a motor fuel in many countries.

In the US the gasohol contains 10% ethanol and 90% gasoline, and became an official fuel in 1978 in Nebraska. The market of ethanol further increased after US Congress had passed legislation requiring the use of oxygenates in gasoline to reduce harmful emission from mobile sources. Global warming, considered the next major environmental front by many people, may further boost the demand for ethanol. Ethanol, being a renewable fuel, produces less green-house-gas emission than gasoline. The Clean Air Act Amendments requires all fuels to contain an average of at least of 2.0 wt% oxygen and winter oxygenated fuels to contain an average of at least of 2.7 wt% oxygen [4].

In the twenties Germany introduced ethanol as a fuel ingredient. The raw material of ethanol was first of all potato. It has been mixed with gasoline up to 25–30%. The 50–65% ethanol content fuel arrived at the mid-twenties through the stock and fuel import abridgements. This ethanol content was too much for the motors, so it was reduced down to 20%. Today the ethanol is not used as motor fuel in Germany [5].

The Brazil 'Proalcool' program was started at the oil crisis of the seventies.

Up to mid of nineties more than a half of the Brazilian vehicle park was rune with pure ethanol, and the remainders with gasohol. Nowadays the rate of the ethanol fuel at the market signs to be decreasing, and the gasohol becomes the main market fuel. The ethanol content of the gasohol is variable, according to the sugar prices at the world market. If the price of the sugar rises, the ethanol content sinks and reverses [6].

In Hungary at the turn of the twenties and thirties it was ruled, that the motor fuel has to contain 20% alcohol to improve the octane number, until the end of the second war [7]. In 2002 the bio ethanol – which has renewable feedstock – used as motor fuel was made tax-free. France and Poland are starting to deal with ethanol as fuel because of agricultural overproduction. They have eliminated the excise of ethanol if it is used as motor fuel. In Poland ethanol was used to bring on the leaded gasoline. In France ethanol is most commonly used in ETBE (Ethyl-tertier-buthyl-ether) as oxygenate. In Sweden the state-aided ethanol price is lower than the gasoline price. Thanks to the flexible distribution network, it is possible to tank 5%, 85% and 100% ethanol content fuel [8]. In the eighties ethanol fleet investigations were made in Austria. The EU Commission has announced its 'Campaign for Takeoff', with a target of going from the current 5 million tons of oil equivalents of liquid bio fuels to 18 million tons in the year of 2010. In the United States, a target has been set to triple the use of ethanol as a propellant from 6 million m^3 at present to 18 million m^3 in 2010.

2.2. *Production*

Fermenting biomass produces ethanol, or grain alcohol, commonly corn (though other, lower-value feed stocks have been tested in an effort to reduce costs, like brewery waste and cheese-factory effluent). Mainly a cooking, fermentation and distillation process using grain crops produces it. Cellulose feed stocks, such as wood and agricultural wastes are considered excellent future candidates for ethanol production [7, 8].

2.3. *Agricultural Benefits*

The introduction of set-aside as a component of EU agricultural policy has made available significant areas of land for which the only agricultural use is production of non-food and non-feed crops. Wheat, maize, potato, sugarcane etc. grown for bioethanol is acceptable for growing on set-aside land, which would otherwise be wasted [6]. Both crops can be autumn ('winter') or spring sown but yields are higher, and the choice of varieties is greater, with autumn sowing. Crops grown for bioethanol production would almost always be autumn sown.

2.4. Environmental Characteristics

The prospect for global warming because of anthropogenic activities is a growing concern in the international community. The combustion of vast quantities of fossil fuel used to satisfy our appetite for energy has released enormous quantities of carbon dioxide into the atmosphere.

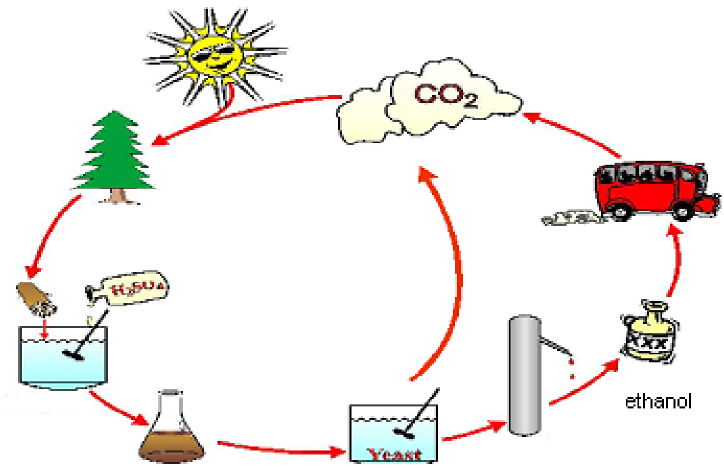

Fig. 1. The closed CO_2 cycle of the biologically produced ethanol [9]

This excess blanket of carbon dioxide traps heat from incoming solar radiation much like a greenhouse. Both corn and cellulosic ethanol produce less GHG emission than gasoline. Biofuels reduce the net carbon emissions to the atmosphere because the carbon dioxide released during biofuel combustion comes from carbon dioxide withdrawn from the ambient environment during the growth stage of the feedstock plants (*Fig. 1*).

The Green House Gas (GHG) reductions for ethanol are modest. Cellulosic ethanol, on the other hand, offers a unique opportunity for releasing virtually no net GHG emission, since the biomass-to-ethanol conversion process makes extensive use of renewable energy [10].

When ethanol is used in a flexible fuel vehicle, it has approximately 30–50 % fewer smog-forming emission than a gasoline vehicle. Air toxics are also reduced about 50 percent when compared to diesel oil. Ethanol also offers significant greenhouse gas benefits, particularly when produced from renewable, high cellulose feed stocks. As all internal combustion engines, vehicles using ethanol emit minor amounts of aldehydes [9].

2.5. Economics (LCA)

As mentioned above, ethanol is produced using food and non-food as feedstock. As a result, the price of ethanol is closely tied to commodity prices of agricultural crops. The ethanol price compared to the diesel oil without subsidies is not competitive. The cabinets support through the ethanol prices the farmers and to externalize the internal benefits: the lower emissions [11].

2.6. Attributes

Ethanol has lesser than two-thirds of the energy density of diesel oil, and has the same limitations as alcohol vehicles. The lower energy density implies that at equivalent engine efficiency, a pure-alcohol-fueled vehicle would travel half to two-thirds as far as a diesel oil-fueled vehicle using the same size tank. The 1999 model year flexible fueled vehicles using E-85 have a driving range of 200–300 miles. The range for these vehicles when using diesel oil is 320–440 miles. These energy density disadvantages can be compensated by certain improvements in efficiency. These can be carried out in spark ignition engines using alcohols, unlike with diesel oil. Pure ethanol can also cause starting problems in cold weather.

The ethanol has a cetin number 8, it is much lower than the diesel oil's 50–55. The air-need of the ethanol is app. 9 kg air pro kg of ethanol (8.4 kg for the E93 ethanol and 7% water content fuel), and this rate is lower than that of the diesel oil, which has an air-need of 14.5 kg. The lower air-need means a possibility to increase the measure of the ethanol without changing the value of the lambda namely the motor optimizing.

Ethanol, as noted above, is a renewable resource that contributes nothing in itself to global warming concerns. Ethanol does not contain sulphur, thus it does not emit any sulphur dioxide. The NO_x emission is lower because of the ethanol's higher vapor heat, which colds the combustion temperature. Ethanol vehicles require lines, hoses and valves resistant to the corrosion that alcohol can induce [12].

Alcohol corrodes lead-plated fuel tanks; magnesium, copper, lead, zinc, and aluminum parts; and some synthetic gaskets. There are no additional changes needed in the distribution network for gasoline, diesel, and natural gas. The ethanol is denatured, to prevent any misuse from ingestion [9, 10].

3. Engine Preparation

To prepare the measurements there were made some technical and financial preparations. The preparations results are as follows [13, 14]:

3.1. Theoretical Air Proportion

We have carried out some pre-calculations to optimize the consistence of the ethanol-diesel mixture. The stochiometrical air need could be calculated from the amount of O_2 that is needed to the reaction. The theoretical equilibrations are presented at (1)–(3) [15] below:

$$C_xH_yO_z = \left(x + \frac{y}{4} - \frac{z}{2}\right) O_2 \rightarrow xCO_2 + \frac{y}{2}H_2O \tag{1}$$

$$O''_{2st,e} = C_2H_5OH = \left(2 + \frac{6}{4} - \frac{1}{2}\right) O_2 = \ 3 \text{ kmol}O_2/\text{kmol ethanol} \tag{2}$$

$$O''_{2st,g} = C_{14.5}H_{30} = \left(14.5 + \frac{3}{4} - \frac{0}{2}\right) O_2 = 22 \text{ kmol}O_2/\text{kmol diesel oil} \tag{3}$$

The molar mass of the fuel is unknown in cases of liquid or solid fuels; only the rate of the components is known. In these cases it is more practical to abstract the oxygen- or air need to one kg fuel. In these equilibrations the contained sulphur was taken into account, but in ethanol is it to neglect (4) and (5):

$$\begin{aligned} O'_{2st,e} &= \frac{c}{12.01} + \frac{h}{4.032} + \frac{s}{32.06} - \frac{o}{32.00} = \frac{0.3531}{12.01} + \frac{0.1764}{4.032} - \frac{0.2352}{32.00} \\ &= 0.0658 \text{ kmol } O_2/\text{kg ethanol} \end{aligned} \tag{4}$$

$$\begin{aligned} O'_{2st,g} &= \frac{c}{12.01} + \frac{h}{4.032} + \frac{s}{32.06} - \frac{o}{32.00} = \frac{0.3531}{12.01} + \frac{0.1764}{4.032} \\ &= 0.1058 \text{ kmol } O_2/\text{kg diesel oil} \end{aligned} \tag{5}$$

with

O'_{2st} – one kg ethanol/diesel oil stochiometrical oxygen need in kmol
c – mass rate of carbon
h – mass rate of hydrogen
s – mass rate of sulphur
o – mass rate of oxygen

From the equilibrations above the calculated air need offers itself on one kg of the fuel:

$K_{LO,e} = 9.0682$ kg air/kg ethanol
$K_{LO,g} = 14.58406$ kg air/kg diesel oil

3.2. Composition of Emission

The stack gas composition could be calculated in the course of whole combustion from chemical equilibrations. In the equilibrations there is used the common form:

$C_xH_yO_z$, which is at the case of ethanol C_2H_6O and at diesel oil is $C_{14.5}H_{30}$. The emitted gases were calculated in *Eq.* (6) and *Eq.* (7).

$$\begin{aligned} C_2H_6O + \left(2+\frac{6}{4}-\frac{1}{2}\right)\cdot(O_2+3.76\ N_2) \rightarrow 2CO_2 + \frac{6}{2}H_2O \\ + 3.76\left(2+\frac{6}{4}-\frac{1}{2}\right) N_2 = 2CO_2 + 3H_2O + 11.28\ N_2 \end{aligned} \tag{6}$$

$$\begin{aligned} C_{14.5}H_{30}\left(14.5+\frac{30}{4}\right)\cdot(O_2+3.76\ N_2) \rightarrow 14.5\ CO_2 + \frac{30}{4}H_2O \\ + 3.76\left(14.5+\frac{30}{4}\right) N_2 = 14.5\ CO_2 + 7.5\ H_2O + 82.72\ N_2 \end{aligned} \tag{7}$$

The molar composition of emitted gases with the further air needs can be determined for ethanol:

$$\begin{aligned} n_{CO_2,e} &= 2\ [\text{kmol } CO_2/\text{kmol ethanol}] \\ n_{H_2O,e} &= 3\ [\text{kmol } H_2O/\text{kmol ethanol}] \\ n_{N_2,e} &= 11.28\ [\text{kmol } N_2/\text{kmol ethanol}] \\ \mathrm{n}_{Gst,e} &= 2+3+11.28 = 16.28\ [\text{kmol emitted gas/kmol ethanol}] \end{aligned}$$

and for diesel oil:

$$\begin{aligned} n_{CO_2,g} &= 14.5\ [\text{kmol } CO_2/\text{kmol diesel oil}] \\ n_{H_2O,g} &= 7.5\ [\text{kmol } H_2O/\text{kmol diesel oil}] \\ n_{N_2,g} &= 82.72\ [\text{kmol } N_2/\text{kmol diesel oil}] \\ n_{Gst,g} &= 14.5+7.5+82.72 = 104.72\ [\text{kmol emitted/kmol diesel oil}] \end{aligned}$$

The mol rate of the components could be calculated by *Eq.* (8)

$$\nu_i = \frac{n_i}{n_{Gst}} \tag{8}$$

where

n_i – mol rate of i. component
n_i – mol number of i. component
n_{Gst} – mol number of the emitted gas

The composition of the emitted gases on the strength of *Eq.* (8) works out:

$$\begin{aligned} n_{CO_2,e} &= 0.1228 & n_{CO_2,g} &= 0.1384 \\ n_{H_2O,e} &= 0.1842 & n_{H_2O,g} &= 0.0716 \\ n_{N_2,e} &= 0.6928 & n_{N_2,g} &= 0.7899 \end{aligned}$$

To determine the molar mass as the emitted gases is used *Eq.* (9).

$$M_V = \sum_{i=1}^{n} \nu_i M_i \tag{9}$$

where

M_V – molar mass of stack gases
M_i – molar mass of i. component
v_i – molar rate of i. component

The mol mass of the stack gases is based on the following:

$$
\begin{array}{llll}
M_{CO_2,e} = 5.4032 & M_{CO_2,g} = 6.0896 \\
M_{H_2O,e} = 3.3156 & M_{H_2O,g} = 1.2888 \\
M_{N_2,e} = 19.3984 & M_{N2,g} = 22.1172 \\
M_{V,e} = 28.1172 & M_{V,g} = 29.4956
\end{array}
$$

The emissions of ethanol run are shown in the first-, and that of the diesel oil runs in the second column. The total amount of emission of ethanol is less than the emission of diesel oil (ethanol 28.1172 mol; diesel oil 29.4956 mol). The repartition of the emitted gases shows that ethanol has brut lower CO_2 emission, and it is not only lower but – if the ethanol is produced from biological feedstock – does not strain the environment.

The investigations of the ethanol-diesel emulsions revealed that the energy density of the ethanol-air mixtures is the same as the diesel oil-air mixtures, according to their different air needs. Due to the engines' ability the quantity of the fuel-air mixture is controlled by the quantity of the fuel. To reach the same power, more ethanol is needed.

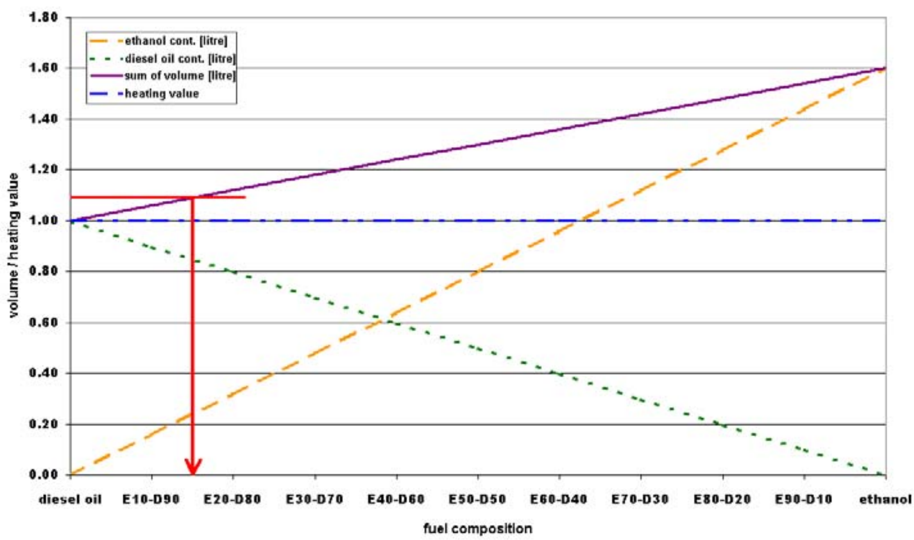

Fig. 2. Function between the injector reserves and the ethanol content of the emulsion [16]

Based on cost optimization and technical grounds the ideal ethanol-diesel oil mixture contains 15% ethanol. This emulsion does not require any components to be changed, while the injector of the chosen RÁBA engine has reserves that could be aimed at approximately 10%. The function between the reserve and the ethanol percent is shown in *Fig. 2*. The abilities of the choosen RÁBA engines are shown in *Table 1*.

Table 1. The abilities of the RÁBA D10 UTLL engine [2]

Manufacturer	RÁBA
Engine type	D10 UTLL 218
Engine No.	604198/192
Piston displacement	10349 cm^3
No. of cylinder	6
Cylinder position	serial, seated
No. of strokes	4
Injector type	Bosch PES/P130A 720RS 7411
Injector No.	1 901 200 898

4. Chosen Measurement Methods

The investigations were carried out in the laboratories of the Institute for Transport Sciences Ltd (KTI Rt.). During the measurements we investigated the influence of the E-diesel on the Rába D10 UTLL 218 direct injection turbocharged engine. The most important measured values were the power, the torque, the consumption and the emission.

4.1. Full Load

The values were measured in the full load investigation in 14 points with both fuels. These points make the envelope curve of the characteristic field. The measurement points located between 800 rpm and 2100 rpm moderate.

4.2. ESC

The ESC cycle is for the vehicular traffic; it was constructed to determine the emission parameters of the CI engines [6]. The cycle contains 13 steady points that are shown in *Fig. 3*.

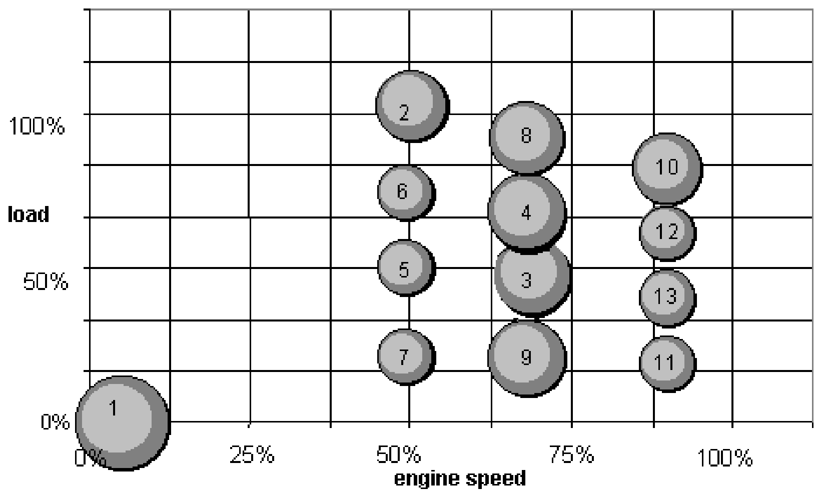

Fig. 3. ESC measurement points [2]

The points above were allocated through the full load measurement. First the engine speeds had to be defined: n_{lo} – where the engine gives the half of the maximal power with full load; n_{hi} – the highest engine speed, where the engine gives 70% percent of the maximal power. Then the three engine speeds could be calculated as follows:

$$A = n_{lo} + 0.25 \cdot (n_{hi} - n_{lo}) \tag{10a}$$
$$B = n_{lo} + 0.5 \cdot (n_{hi} - n_{lo}) \tag{10b}$$
$$C = n_{lo} + 0.75 \cdot (n_{hi} - n_{lo}) \tag{10c}$$

4.3. EGB 96

The EGB 96 cycle models the work of the agricultural machines. The cycle contains 8 points that are shown in *Fig. 4*.

5. Summary

On the whole, the ethanol-diesel oil mixtures have promising abilities to substitute the pure diesel oil. By chosen mixture with 15% ethanol content the main abilities of the E-Diesel could be well visualized, and it could be used in the frequently used RÁBA engines without any modifications. The results of the investigations will be demonstrated in the second article.

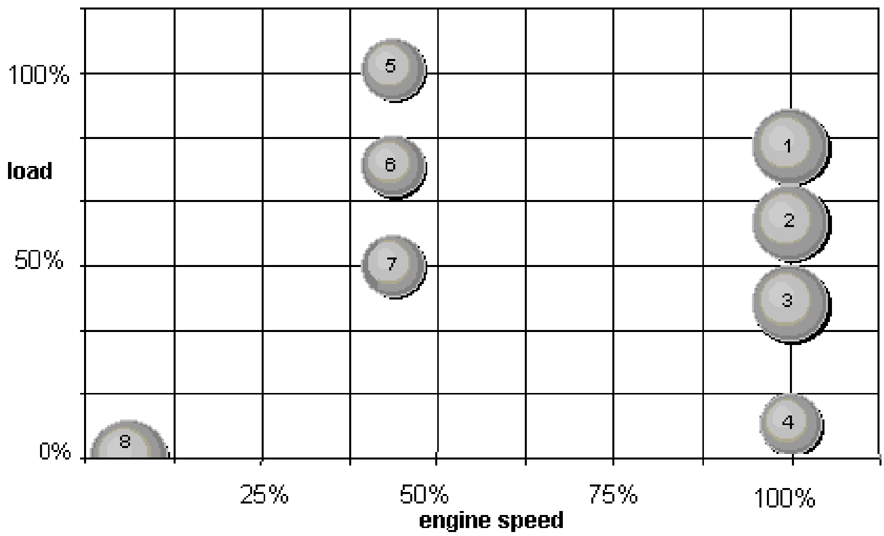

Fig. 4. EGB 96 Cycle [1]

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